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First Year's Results and Field Experience With the Latest JILA Absolute Gravimeter

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Abstract

One of the six absolute gravity instruments developed and built by the Joint Institute for Laboratory Astrophysics (JILA) between 1982 and 1985 has been tested under a variety of environmental conditions between May 1987 and 1988. Of the 30 sites visited during this period, 10 were occupied more than once. These reobservations indicate repeatability between 1 and 4 microgals.

1. Introduction

The National Geodetic Survey (NGS), in cooperation with the Defense Mapping Agency, Hydrographic and Topographic Center (DMAHTC), has been testing the field performance of one of the latest JILA absolute gravimeters, JILAG#4. Absolute gravity has been observed in eight east coast states; California; on the Hawaiian islands of Kauai, Maui, and Oahu; on Bermuda; and at Gatineau, near Ottawa, Canada. Rather than seeking rapid station occupations and sites with marginal environmental stability, the emphasis was placed on getting the best repeatability. Based on the laboratory performance of these instruments [Niebauer 1987 and Niebauer et al., 1986], it was expected that under ideal conditions repeatability of better than ±3 microgal could be obtained. To achieve such repeatability, a set of procedures for site selection, data collection, quality control, and corrections for the effects of environmental changes has been developed.

2. Site Selection

In addition to broad geological considerations, site selection was guided by three principal criteria. To provide a solid foundation for the instrument and to avoid the problem of groundwater table changes on gravity, we looked for buildings set on nonporous bedrock. In addition, buildings were selected in which vibrations introduced by human activity were judged to be relatively low. The instrument was set up in a room at or below ground level, where temperature fluctuations were also expected to be minimal.

It was found that few of these desired environmental conditions could be adequately prejudged. A good, after the fact, measure of the vibrations was the scatter of the individual drops from the mean in the given drop-sets. At the quietest sites, the standard deviation of the drop-sets was in the 5-10 microgal range, at the noisiest sites in the 50-70 microgal range (given 250 drops for a set). The most common range was 15-30 microgal.

However, even at the noisiest sites, the mean of the successive drop sets stayed in the 5-10 microgal range. The principal problematic vibration sources were air conditioning equipment, and at our island sites, the oceanic microseisms.

Inadequate temperature stability was the most likely cause for the up to 15 microgal differences among the means of successive drop sets at some of the seismically quietest sites. Large temperature variations, particularly when the temperatures climbed to 27 C° - 29 C°, could have affected the laser lock mode frequencies and the initial position of the dropped object. In addition, cooling down at night several times caused the bottoming of the mass of the superspring, causing unacceptable drop-to-drop scatter.

Changes of the groundwater table can be a major source of error in repeat gravity observations. Presently at three of our sites where the influence of groundwater table variation is a concern, the water table is monitored and corrections are applied to compensate for the consequent mass variations. The majority of the remaining sites are free from this effect. The few sites at which the groundwater table cannot be monitored will not be used for the investigation of the temporal changes of gravity.

3. Field Observations and Quality Control

The current field observations consist of the collection of drop sets (containing 250 drops) at 2 hour intervals for 2 days. The histograms of these drop sets approach Gaussian, and the drop set means are well defined. To minimize the change of the frequencies of the laser lock modes due to environmental effects, the laser lock mode is switched after every drop set. Environmental corrections are added either to each drop, the drop set means, or to the mean of all drop sets. The 2-day-long observations at a station minimize the errors left in the data after the application of the corrections.

To eliminate outliers caused by high random noise events, each drop set first is screened, and all drops exceeding three standard deviations from the mean are rejected. Although rarely more than three drops are rejected, the mean of the drop sets often changes by 3 microgals due to this process. After this quality control process, the corrections are added and the weighted mean of all drop sets is computed (using the variance of the drop-sets as weight) to obtain the gravity value of a station.

4. Corrections

The largest environmental correction is for the solid Earth tide, which is computed by the gravimeter controller using Longman's [1959] formulation. In post processing, this correction is replaced by the more accurate formulation of Tamura [1982], which eliminates the 3 to 4 microgal errors of the

previous program. The atmospheric attraction and loading are corrected for by using the approach of VanDam and Wahr [1987], the U.S. Standard Atmosphere [Boedecker et al., 1979], and regional pressure [Rabbel and Zschau, 1985] for absolute station pressure reference. This correction can amount to as much as 5 microgals. To correct for the effect of ocean loading, unpublished programs of T. Sato and H. Hanada and of D. Agnew have been adapted. At some coastal sites, the computed amplitudes had to be reduced to match the observed signal. While this correction to the individual drop sets had varied between 2 to 10 microgals, the actual change to the computed gravity value was usually a few tenths of microgals at the interior and 2-3 microgals at the coastal sites. Because, by coincidence, the repeat observations were made in the same season, the water table changes to date have resulted in only about 2 microgal corrections. The effect of the seasonal peak-to-peak change at the Herndon site would have been 13 microgals. We also corrected the observed gravity values for the changes of the Earth's rotational axis by converting the gravity value to the mean pole position. The magnitude of this correction for the half Chandler period is about ±9 microgals.

Instrumental corrections involved laser aging and laser temperature effects, and conversion to the same measurement height in case of repeat observations. While laser frequency drift due to aging is well defined, imprecise temperature corrections could contribute 2 microgals to the overall error budget, which in the majority of cases was under 6 microgals. This uncertainty estimate includes the 0.03 microgal/cm vertical gradient determination error.

5. Instrumental Problems

So far, the JILAG#4 gravimeter has undergone a major checkup twice a year. The instrument was taken apart, and repairs, replacements, readjustments and calibrations were made. Field problems included: 1) partial vacuum loss due to failure in the portable power supply; 2) electronic component failures, short circuits, and readjustments involving the dropping chamber and super spring controllers and the dropped object wiring harness; 3) data and time loss due to bottoming of the mass of the super spring and due to drift of the reference level (carriage lock position), both caused by excessive temperature changes (larger than ±3 C°).

6. Results

Site description and absolute gravity values may be obtained from NGS by writing to the authors. Details on the absolute gravity program and on the first year's results are available in Peter et al. [1988] and in Peter et al. [in press]. The National Geodetic Survey now uses absolute gravity observations in conjunction with GPS and VLBI observations to monitor vertical crustal motion.

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